Structure of atomic hydrogen

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Abstract: Present-day atomic theory suggests that electrons in an atom exist around the nucleus as standing matter-waves (or electron clouds) in inner and outer orbitals. However, because this behavior requires electrons to be constantly moving, and because there is no evidence that electrons display this kind of motion, the present-day atomic theory may not be accurate. Here I discuss a conceptual experiment, involving the interaction of light with hydrogen gas, which leads us to assume that, contrary to the present-day belief, the electrons or nuclei in the atoms of a medium have no role in the transmission of light through that medium, and that atoms contain another state of matter which acts as this transmission medium for light and slows down the light's speed (reason for the refraction of light). This leads us to consider an alternative model of the atom that is more consistent with experimental results. This communication proposes a new atom model for hydrogen, which can provide new insights into such phenomena of how a hydrogen atom creates its spectral lines and how the splitting of spectral lines occurs, among others.

Keywords: atomic structure, new atomic theory, hydrogen atom

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Bohr developed his atomic model [1,2] based on the concept that electrons are rapidly moving around the nucleus, which was proposed by Rutherford [3], followed by the Geiger–Marsden experiment [4]. Inspired by Einstein's explanation of the photoelectric effect [5] by considering light to behave as a particle, which was previously thought to act only as a wave, de Broglie developed the matter-wave theory [6], which suggested that moving particles also have the same dual nature as light. The concept of electron motion around the nucleus and the matter-wave theory led Heisenberg to propose the Uncertainty principle [7] and Schrödinger to propose the Wave function equation [8] and these resulted in the development of the currently accepted Atomic Orbital Model (or Wave Mechanical Model) of the atom [9]. According to this model, an atom's electrons exist around the nucleus as standing matter-waves (or electron clouds) in inner and outer orbitals, which have different energy levels. However, although the Geiger–Marsden experiment provided evidence that the atom has a nucleus, the experiment did not provide any information about the "status" of the electrons. At the same time, the matter-wave theory was verified using artificially accelerated electrons [10,11]. In short, there is no evidence that electrons exhibit continuous motion around the nucleus, and therefore we cannot consider that the electrons act as matter-waves (or standing waves), the behavior which the electrons demonstrated in the matter-wave experiments. Hence, there remains a need for still more studies designed to probe the structure of the atom.

Similarities can be seen between an electrical resonator (ER) circuit and an atom. An ER circuit absorbs and emits only those radio waves that match the resonant frequency of the circuit. Similarly, at low-temperature and low-pressure, free atoms of an element absorb from a continuous spectrum (CS) of light only those photons whose wavelengths are included in the line spectrum of that element and emit photons at these same wavelengths. From this, we can understand that, like the free electrons in an ER circuit, the electrons in an atom are also situated in some kind of resonant columns. At the same time, as a divergence from an ER circuit, because an atom of an element absorbs and emits a large number of different wavelength photons, the atom must contain a large number of resonant columns. An ER circuit emits radio waves because of the vibration of

electrons in that circuit. By analogy, we can posit that an atom emits photons because of the vibration of electrons in that atom.

According to the present-day belief, the electrons in the atoms of a transparent medium are primarily responsible for transmission of light through that medium [12]. The vibrating electromagnetic field of the incident photons induce motion in the electrons in the atoms of the medium to vibrate at the incident photon frequencies, which causes the electrons to re-create photons in the incident photon frequencies. Light is transmitted as the result of this kind of interaction of photons with the electrons and the re-creation of photons within the medium. It is also believed that this kind of interaction between light and electrons is the reason for the slightly reduced speed of light in a medium.

Here we consider the interaction between light and hydrogen gas (HG). When a CS of light impinges on HG at an angle perpendicular to the HG interface (HG is contained in a transparent container), which is at low-temperature and low-pressure, only photons with wavelengths present in the hydrogen line spectrum are absorbed, while the rest of the photons will pass in a straight line through the HG, at a speed slightly less than the speed of light (*c*) [see Fig. 1(a)]. [The speed of light with a wavelength of 589.3 nm in HG, at a pressure of 101325 Pa and temperature of 0 °C, $v = {}^{c}/_{n}$ = $\frac{2.99792458\mathrm{x}10^{8}}{1.000132}\mathrm{m}/s$ = $2.99752890\mathrm{x}10^{8}\mathrm{m}/s$, where *n* is the refractive index of hydrogen [13] and *c* is the speed of light in a vacuum]. Photons with the same wavelength of the absorbed photons are emitted in different directions. As those photons with wavelengths matching the hydrogen line spectrum are incident on the HG, the electron in each of the hydrogen atoms (HAs) vibrates in free orientations. This is the reason why HG emits photons in the above stated manner [Fig. 1(c)]. However, it may not be reasonable to think that the electrons in the HAs which vibrate in free orientations, and emit photons in different directions, when they interact with one group of photons, could vibrate in such a way that these vibrations could guide another group of photons through the HG in a straight line as the electrons interact with them.

If the CS of light is incident on a high-pressure HG, more different wavelength photons will be absorbed and thus the number of different wavelength photons that pass straight through the HG will be reduced [Fig. 1(b)]. This indicates that, as pressure increases,

more different wavelength photons interact with the electrons in the HAs and only photons which do not interact with the electrons pass straight through the HG. This also implies that electrons in the HAs in fact have no role in the straight-line transmission of light through the HG. At the same time, it is also not reasonable to think that the nuclei of atoms of a medium, which are more massive and require more kinetic energy to vibrate, help the transmission of light through that medium. These facts indicate the presence of another state of matter in atoms, which acts as a transmission medium for light and influences the light's speed.

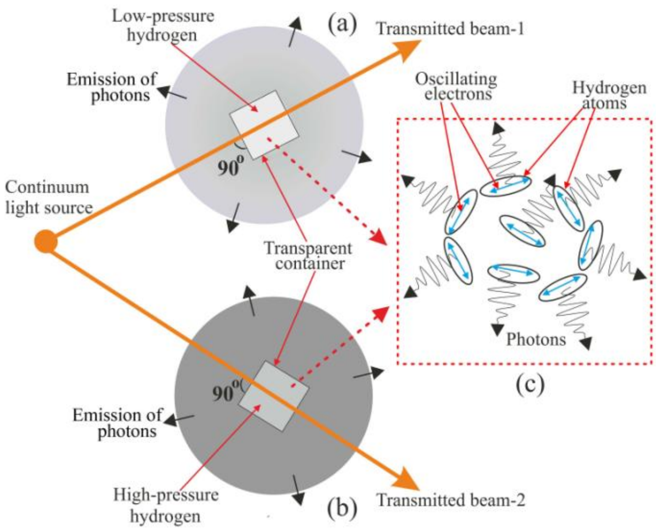

FIG. 1. (a) At low-temperature and low-pressure, HG absorbs and emits only photons with wavelengths present in the line spectrum of hydrogen. The transmitted beam-1 consists of all wavelength photons that are not included in the hydrogen line spectrum. (b) High-pressure HG absorbs and emits photons with more different wavelengths. The transmitted beam-2 consists of a less number of different wavelength photons. Both beams are incident normal to the surfaces of the transparent HG containers and pass in straight lines through the HGs. (c) HG emits photons in different directions.

This matter plays the following roles in the structure of a HA. 1) Endows HA with volume: The charge radius of the nucleus (proton) of a HA (R_p) is only $0.8775(51)\times10^{-15}$ m [14,15]; however, the value of the Bohr radius (a_0) = $5.2917721092(17)\times10^{-11}$ m [14,15] {the radius of a HA is greater than even this value [ref. Fig. 2(a)]}. 2) Prevents the electron from falling into the nucleus: Although there is an attractive force of 8.22×10^{-8} N between the nucleus and the electron, the electron does not collapse into the nucleus.

[$Fe = k\frac{q_e q_p}{r^2}$ = $(8.99\text{x}10^9\,\text{Nm}^2/\text{C}^2)\frac{(1.60\text{x}10^{-19}\,\text{C})(1.60\text{x}10^{-19}\,\text{C})}{(5.29\text{x}10^{-11}\text{m})^2}$ = 8.22×10^{-8} N,

where *Fe* is the magnitude of the electric force, *k* is the electrostatic constant, q_e and q_p are the charges of electron and proton [14,15], respectively, and r is the Bohr radius]. 3) Creates resonant columns (we saw that the electrons in an atom are situated in some kind of resonant columns). Because the space inside an atom is filled with this matter, we refer to this matter as space matter (SM).

Electron collision experiments can provide much important information about the structure of an atom. While the collision of low-energy electrons on a multi-electron atom causes the emission of only long-wavelength photons, a collision of high-energy electrons on the same atom results in the emission of short-wavelength photons. For example, as the collision energy of electrons in an X-ray tube increases, the wavelength of photons that are emitted by the target of the X-ray tube decreases. At the same time, if the colliding electrons have sufficient energy, an atom emits the shortest wavelength photons that the atom can emit. We know that inner electrons emit short-wavelength photons. While low-energy electrons are only able to excite outer electrons of an atom, high-energy electrons penetrate through the outer regions of an atom and excite inner electrons. This indicates that the SM density is lower in the outer regions of an atom and increases with decreasing distance from the nucleus. We can assume that this difference in the SM densities is the reason for the low-frequency resonant frequencies for outer regions and high-frequency resonant frequencies for inner regions of an atom. At high-temperature and high-pressure atoms of an element produce large numbers of spectral lines compared with their elemental spectral lines, which indicates that an atom contains a large number of resonant columns in it. Because these large numbers of resonant columns act as thin layers, we can consider a resonant column as a thin shell.

An atom consists of three types of shells. 1) Electron shells (ES): These are the regions in which the electrons in a non-excited atom are situated. HA has only one ES [see Fig. 2(b)]. Since the buoyant force exerted by the ES and the force of attraction between the nucleus and the electron are equal, the electron in a non-excited HA is situated in its ES. In effect, the electron in a HA cannot go beyond the ES and reach any closer to the nucleus. 2) Transitory shells (TSs) – simply “shells”: When an electron in an ES is

excited, because the density of the SM is higher in the inner regions, the electron will be expelled to an outer, low-density SM region. These regions to which the electrons are expelled are TSs.

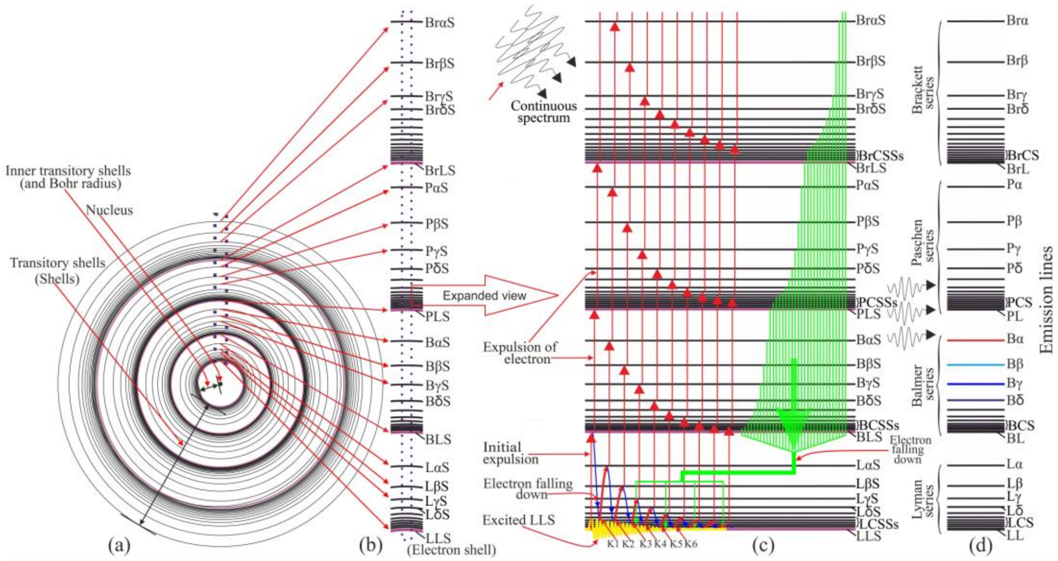

FIG. 2. (a) Cross-sectional diagram of the hydrogen atom (illustrates Lyman shell series to Brackett shell series). As the distance increases from the nucleus, the density of the SM decreases. (b) Enlarged view of the highlighted portion of the diagram in (a). (c) Expanded view of the highlighted portion of the diagram in (b); it illustrates the excitation of the electron from inner regions to outer regions, and the relaxation of the electron back from outer regions to the Lyman limit shell (LLS). (d) Formation of the hydrogen atom line spectrum.

We know that, although HA has only one electron, a HA can emit and absorb photons of different wavelengths. All of the photons, excluding the shortest wavelength photons, that are emitted by a HA are emitted from its TSs. 3) Inner transitory shells (ITSs): These are the shells that are situated in the inner regions of the innermost ES [TSs and ITSs of hydrogen atom are shown in Fig. 2(a)].

Here we examine how a HA creates its absorption and emission spectra from a CS of light. The electron of a HA, in a low-temperature and low-pressure HG, is situated in the ES [see Fig. 2(b)]. Since the shortest wavelength photon that can be emitted by a HA is the Lyman limit (LL) photon, we can surmise that the frequency of the LL photon is the resonant frequency of the ES of a hydrogen atom. Here, because the LL photon is emitted from the ES of the HA, we refer to this ES as the Lyman limit shell (LLS). If a photon from within the CS that has the same wavelength of a LL photon interacts with the electron of a non-excited HA, the electron will absorb that photon and the LLS will become excited [see excited LLS in Fig. 2(c)]. As a result, the electron will emit a new LL

photon [see LL in Fig. 2(d)] and will be expelled to an outer region [see initial expulsion Fig. 2(c)]. However, because of its attraction to the nucleus, when the expelled electron reaches the Balmer limit shell (BLS) [i.e., the shell from which the Balmer limit (BL) photon is being emitted], the speed of the electron will be reduced to zero, and the electron will start to return to the LLS. This brief pause of the electron motion creates an opportunity to interact with a photon within the CS that matches the wavelength of a BL photon, and that photon will be absorbed and the BLS will become excited. As a result, the electron will emit a new BL photon [see BL in Fig. 2(d)] and will be expelled to Paschen limit shell (PLS) [see PLS in Fig. 2(c)]. This process will be continued further to other outer shell series of the Paschen shell series. In this way, if the electron, which is situated either in the LLS or is expelled from an inner shell to an outer shell, is excited by interacting with an appropriate wavelength photon, a new photon—with the wavelength of the interacting photon—will be emitted and the electron will be expelled to the excited shell's next corresponding shell in the outer series.

However, if the electron which is expelled from an inner shell to an outer shell is not excited again, because of the attraction from the nucleus, it returns back to the LLS. If an electron that has been expelled to the BLS relaxes to the LLS in this way [see falling down of electron Fig. 2(c)], because the interval between the expulsion from the LLS and the return to the LLS is minimal, as the amplitude of the damping oscillation of the LLS is sufficient, the electron will be kicked [see K1 in Fig. 2(c)] to the Lyman alpha shell (LαS). If this electron, which is kicked to the LαS, interacts with a photon in the CS with the wavelength of a Lyman alpha (Lα) photon, it will emit a new Lα photon [see Lα in Fig. 2(d)] and will be expelled to the Balmer alpha shell (BαS) [see BαS in Fig. 2(c)]. Moreover, if the electron which is expelled to the BαS interacts with a photon in the CS with the wavelength of a Balmer alpha (Bα) photon, it will emit a new Bα photon [see Bα in Fig. 2(d)] and will be expelled to the Paschen alpha shell (PαS) [see PαS in Fig. 2(c)].

However, if the electron which is kicked to the LαS is not further excited, it will again fall back to the LLS, and as the result of the oscillation of the LLS – now with a slightly reduced amplitude because of the damping – the electron will be kicked to the Lyman beta shell (LβS) [see K2 in Fig. 2(c)]. If the electron which is kicked to the LβS is excited,

it will emit a new Lyman beta (Lβ) photon [see Lβ in Fig. 2(d)] and will be expelled to the Balmer beta shell (BβS). At the same time, because the amplitude of oscillation of the LLS is decreasing with time, as the interval increases between the expulsion (or kick) of the electron from the LLS and the relaxation to the LLS, the electron will be kicked only to an outer shell which is closer to the LLS. In this way, the excitation of the shells that are closer to the LLS [see Lyman gamma shell (LγS), Lyman delta shell (LδS), etc. and the Lyman Continuous Spectrum Shells (LCSSs) in Fig. 2(c)] to which the electron is kicked [see K3, K4 etc. in Fig. 2(c)], causes the emission of Lyman gamma (Lγ) photon, Lyman delta (Lδ) photon, etc. and also the emission of the CS in the Lyman series [see Fig. 2(d)]. At the same time, as a result of these kinds of excitations, the electron will be expelled to the Balmer gamma shell (BγS), Balmer delta shell (BδS), etc., and also to shells that are very close to the BLS, from which the CS in the Balmer series are emitted [see Fig. 2(c)]. However, if the expelled (or kicked) electron from the LLS takes more time to fall back to the LLS, as LLS loses its excitation with time, the electron will not receive a kick from the LLS. This results in the electron interacting with a photon that is in the CS with the wavelength of a LL photon, and causes the excitation of the LLS and the emission of a new LL photon, followed by the expulsion of the electron to the BLS.

Because atoms with identical nuclear structures have the same shell-structure, at a defined distance from the nucleus, the SM density for these atoms will also be the same. Therefore, electrons that are expelled from a specific inner shell of all such atoms will reach outer-shells having the same resonant frequency, and when these shells get excited, the electrons will emit the same wavelength photons. In short, identical atoms create identical spectral lines.

Because an external field influences the expulsion of electrons in atoms, when an atom is excited in the presence of an electric field or magnetic field, the electrons will be expelled from inner-shells to different outer-shells, instead of the outer-shells to which the electrons normally get expelled (also, because a field influences not all atoms uniformly, the expulsion of electrons in different atoms of the same element will be slightly different). Such atoms produce slightly different spectral lines instead of their original spectral lines. This is the reason for Zeeman-splitting [16] and Stark-splitting [17]. As stronger fields

have a greater influence on the electrons, a stronger field causes the splitting to be broadened. At the same time, weak electric fields and magnetic fields produced by electrons and nuclei of atoms cause splitting in the spectral lines of neighboring atoms. These kinds of splitting, which can only be observed under high magnification, are fine-structure and hyperfine-structure.

More studies are needed to understand the formation of shells around the nucleus, chemical reactions, atomic-level explanation for magnetism, etc. However, the new understanding that the nucleus of an atom is enveloped by a new state of matter, and that this matter plays a key role in the structure of atoms, will aid in the advancement of nano-scale, nuclear fusion, and other emerging technologies. Also, the knowledge of this new matter, and the fact that light-speed is altered when light is passed through this matter, allows a deeper understanding about light-matter interactions and ultimately about the cosmos itself.

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